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## DESCRIPTION

ELECTROMAGNETIC WAVE SHIELDING KNITTED MATERIAL AND  
ELECTROMAGNETIC WAVE SHIELDING GARMENT

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TECHNICAL FIELD

The present invention relates to an electromagnetic wave shielding knitted material and an electromagnetic wave shielding garment, which protect the human body from the influence of electromagnetic waves leaked from cellular telephones, microwave ovens, CRTs of televisions and personal computers or other electronic equipment that generates electromagnetic waves, and electromagnetic fields radiated from antennas of cellular telephones, radio equipment and like equipment placed in the vicinity of the human body. The electromagnetic wave shielding knitted material and electromagnetic wave shielding garment according to the present invention not only protect the human body from the influence of electromagnetic waves, but also effectively prevent electromagnetic waves from causing malfunction of medical devices implanted in the body, such as pacemakers.

BACKGROUND OF THE INVENTION

As a conventional measure to prevent damages by electromagnetic waves emitted from an electromagnetic source, a metal net or like electromagnetic wave blocking

layer is wrapped around the electromagnetic source to prevent leakage of electromagnetic waves. However, with the recent development of electronic equipment, electromagnetic sources greatly increase in number and become more and more miniaturized. Accordingly, attempts have been made to provide an electromagnetic source with an electromagnetic wave shielding net (layer) to prevent leakage of electromagnetic waves. For this purpose, Japanese Unexamined Patent Publication No. 1998-168702, Japanese Utility Model No. 3010147, Japanese Unexamined Patent Publication No. 1996-176962 and Japanese Unexamined Patent Publication No. 1998-292252 disclose knitted or woven electromagnetic wave shielding nets (knitted or woven fabrics) made of lightweight, flexible conductive fibers developed for use as an electromagnetic wave blocking film or as an equipment's built-in electromagnetic wave shielding net.

However, the disclosed techniques are not capable of completely shielding electromagnetic wave sources. Moreover, electromagnetic wave emission is essential in some equipment, such as radio equipment. Therefore, shielding measures only on electromagnetic wave sources are clearly insufficient.

Thus, there is a necessity for an electromagnetic wave shielding measure with a garment for

the human body. Electromagnetic wave shielding garments should have comfortable wearability as well as high electromagnetic wave attenuation efficiency. Some electromagnetic wave shielding garments have been proposed  
5 which consist merely of conductive fibers, but these garments are poor in softness, drapability, bulkiness, compression characteristics and like characteristics that determine so-called "hand". Thus, these garments are not only unsatisfactory in basic requirements such as sweat  
10 absorbency, but also liable to cause skin disorders (allergies) due to metals contained in conductive fibers. Accordingly, a measures to solve these problems has been strongly desired.

Japanese Unexamined Patent Publication No. 1998-  
15 77507 proposes a garment comprising a natural or chemical fiber knitted or woven together with a conductive fiber.

Further, Japanese Unexamined Patent Publication No. 1999-50352 proposes a fabric having both  
20 electromagnetic wave shielding capability and metal allergy resistance, the fabric being obtained by covering a conductive fiber as stuffing thread with a nonconductive fiber so that the conductive fiber is out of direct contact with the skin.

However, although the garment disclosed in  
25 Japanese Unexamined Patent Publication No. 1998-77507 is

reduced in the amount of direct contact of the conductive fiber with the skin, the conductive fiber still partially comes into direct contact with the skin. Accordingly, the garment is unsatisfactory in view of its unpleasant

5 wearing feeling and metal allergy resistance. On the other hand, the fabric disclosed in Japanese Unexamined Patent Publication No. 1999-50352 is free from the above problems since the conductive fiber used therein does not come into direct contact with the skin. However, there is  
10 a further demand for decreasing the amount of conductive fiber to be used for reducing the cost, since conductive fibers are generally extremely expensive.

Japanese Examined Utility Model Publication No. 1992-54165 discloses an undergarment which is always  
15 wearable, obtained by sewing a knitted or woven fabric laminate comprising a knitted or woven fabric made of a conductive fiber and a knitted or woven fabric made of a highly hygroscopic fiber for normal clothes, in such a manner that the highly hygroscopic fabric comes inside the  
20 undergarment. However, the publication nowhere discloses specific means for imparting an effective electromagnetic wave shielding capability to the knitted or woven fabrics.

Conventionally, in specifications of  
electromagnetic wave shielding garments, electromagnetic  
25 shielding properties of an electromagnetic wave shielding

garment comprising a conductive fiber yarn were measured using a material piece of the garment, by widely known KEC method, Advantest method or like method using an apparatus for measuring and evaluating electromagnetic wave

5 shielding properties, in order to prevent the influence of electromagnetic waves on the human body and on medical equipment implanted in the human body.

However, even if the material piece has a desired electromagnetic wave shielding capability, the  
10 garment sometimes does not have the desired electromagnetic wave shielding capability, due to diffraction, infiltration, etc. of electromagnetic waves, depending on the garment shape.

The present invention has been accomplished in  
15 view of the above situation. An object of the present invention is to provide a material for clothes which gives no unpleasant feeling when being put on, causes no skin disorder due to metal allergy, and contains less amount of conductive fiber while maintaining electromagnetic wave  
20 shielding capability, so as to achieve reduction in cost.

A further object of the present invention is to provide an electromagnetic shielding garment free of influence of diffraction, infiltration, etc. of electromagnetic waves, the garment being obtainable by  
25 measuring electromagnetic shielding capability as a

garment, and designing and making a garment shape to achieve a desired electromagnetic wave shielding capability.

BRIEF DESCRIPTION OF THE DRAWINGS

5            Fig. 1 is a graph showing the relation between cotton count and shielding capability in Example 1.

            Fig. 2 is a graph showing the relation between cotton count and G-soft in Example 1.

10           Fig. 3 is a graph showing the relation between cotton count and shielding capability in Example 2.

            Fig. 4 is a graph showing the relation between cotton count and G-soft in Example 2.

15           Fig. 5 is a front view of an embodiment of the electromagnetic wave shielding knitted material of the present invention.

            Fig. 6 is a graph showing the relation between electromagnetic wave shielding capability and cost.

20           Fig. 7 is a diagram of a measurement system for an apparatus for measuring and evaluating electromagnetic wave shielding properties as a garment.

            Fig. 8 shows the result of electromagnetic field distribution analysis of the short-sleeved, round-necked undershirt model obtained in Example 5.

25           Fig. 9 shows the result of electromagnetic field distribution analysis of the short-sleeved, V-necked

undershirt model obtained in Example 6.

Fig. 10 shows the result of electromagnetic field distribution analysis of the collard shirt type garment model obtained in Comparative Example 3.

5 Fig. 11 shows the result of electromagnetic field distribution analysis of the vest type garment model obtained in Comparative Example 4.

Fig. 12 shows the result of electromagnetic field distribution analysis of the dummy of the human body  
10 without an electromagnetic wave shielding garment in Comparative Example 5.

#### DISCLOSURE OF THE INVENTION

The present invention provides the following electromagnetic wave shielding knitted materials and  
15 electromagnetic wave shielding garments.

1. A reversible electromagnetic wave shielding knitted material comprising a conductive fiber yarn as a surface side and a natural fiber yarn as a back side.

2. A material according to item 1, which  
20 comprises a plain knitted structure or rib knitted structure obtained by plating the conductive fiber yarn and the natural fiber yarn in all the courses of the knitted material.

3. A material according to item 1, wherein the  
25 conductive fiber yarn is a multifilament in which each

filament comprises a nylon fiber, a polyester fiber, an acrylic fiber, a polypropylene fiber or like synthetic fiber having a denier (d) of about 2 to about 8, and a metal component applied to a surface of the synthetic  
5 fiber by sputtering, vacuum deposition, electroless plating or like method.

4. A material according to item 1, wherein the conductive fiber yarn is a fiber of polyacetylene or like conductive resin, or a fine wire of gold, silver, copper,  
10 stainless steel or like metal.

5. A material according to item 1, wherein the natural fiber yarn comprises a natural fiber, a natural fiber/ rayon fiber mixed spun yarn, or a natural fiber/ synthetic fiber mixed spun yarn.

15 6. A material according to item 1, wherein the conductive fiber yarn is a silver-plated nylon yarn having a denier (d) of about 70 to about 210, and the natural fiber yarn is a cotton yarn having a count of 30 to 150, the material having a KES hand value (G-soft) of at least  
20 6 and an electromagnetic wave shielding capability of at least 20 dB.

7. A material according to item 1, which comprises, as the surface side, the conductive fiber yarn and an elastic fiber yarn interknitted with each other.

25 8. A material according to item 7, wherein the



elastic fiber yarn is a single-covered yarn or a double-covered yarn comprising a polyurethane thread as a stuffing thread covered with a nylon thread.

9. A material according to item 7, wherein the  
5 elastic fiber yarn has a denier (d) of about 10 to about 200.

10. A material according to item 7, wherein the proportion of the elastic fiber yarn is greater than 0 but not greater than  $2/3$  of the total amount of the conductive  
10 fiber yarn and the elastic fiber yarn interknitted with each other.

11. A material according to item 1, which is used as an undergarment.

12. An electromagnetic wave shielding garment  
15 obtainable by: measuring electromagnetic wave shielding capability as a garment using an apparatus for measuring and evaluating electromagnetic wave shielding capability comprising a measurement system in the shape of the upper part of the human body for measuring electromagnetic wave  
20 shielding capability as a garment in the state of being worn by the human body; designing a garment shape to obtain a desired electromagnetic wave shielding capability; and making a garment of the designed shape.

13. An electromagnetic wave shielding garment  
25 according to item 12, wherein the apparatus for measuring

and evaluating electromagnetic wave shielding capability comprises: a signal transmitter for emitting a high-frequency signal; a transmission antenna connected to the high-frequency signal transmitter for radiating a high-frequency electromagnetic field into a free space; a dummy which is similar to the human body in shape and electric constants including dielectric constant and magnetic permeability; a receiving antenna provided at a predetermined position within the dummy for receiving the high-frequency electromagnetic field, the receiving antenna being equivalent in impedance to the human body and similar in shape to a lead wire of a device surgically implantable in the human body; and a signal receiver connected to the receiving antenna for receiving the high-frequency signal.

14. A garment according to item 12, which has an electromagnetic wave shielding capability as a garment of at least 15 dB when the distance between the transmission antenna and the surface of the dummy is 5 cm, at least 18 dB when the distance is 10 cm, and at least 20 dB when the distance is 20 cm, relative to the amount of electromagnetic waves received by the dummy without the garment.

15. An electromagnetic wave shielding garment according to item 12, which has such a shape that forms no

gap when worn.

16. An electromagnetic wave shielding garment according to item 15, wherein the shape that forms no gap is an undergarment or a T-shirt.

- 5           17. An electromagnetic wave shielding garment according to item 12, which prevents electromagnetic waves from causing cardiac pacemaker malfunction.

Since the knitted material of the present invention is used as a garment (in particular, an  
10 undergarment), the material has a reversible structure in which the side close to the skin comprises a natural fiber yarn. To obtain such a structure, a conductive fiber and a clothing fiber are fed to a plain knitting machine or a rib knitting machine in such a manner that the conductive  
15 fiber is covered with the clothing fiber. For example, plating of a conductive fiber yarn and a natural fiber yarn is carried out in all the courses so that the natural fiber yarn comes to the side close to the skin.

Examples of conductive fiber yarns for use in  
20 the invention include yarns made of fibers of polyacetylene or like conductive resin; yarns obtained by applying polyacetylene or like conductive resin to a synthetic fiber such as nylon, polyester, acrylic or polypropylene; yarns obtained by applying gold, silver,  
25 copper, nickel or like metal component by vacuum

deposition, sputtering, electroless plating or like method; and fine wires of stainless steel, gold, silver, copper or like metal. Particularly preferred are yarns obtained by electrolessly plating a synthetic fiber with  
5 silver.

Specific examples of conductive fiber yarns include X-Static (tradename of Sauquit) comprising a nylon multifilament plated with silver.

Preferably, each filament of the conductive  
10 fiber yarn has a denier (d) of about 2 to about 8, and the conductive fiber yarn has a denier (d) of about 70 to about 210.

Examples of natural fiber yarns include yarns of cotton, silk, hemp or the like; and yarns of rayon, Lyocel, Tencel or like regenerated fiber; yarns of acetate, diacetate or like semi-synthetic fiber; and yarns of acrylate, modified nylon or like hygroscopic synthetic fiber with satisfactory comfortableness as an undergarment. The natural yarn for use in the invention is not limited  
20 to the above examples, and include rayon staple fiber spun yarns, natural fiber and rayon fiber mixed spun yarns, and natural fiber and synthetic fiber mixed spun yarns. Using any of these yarns, a knitted garment (in particular, an undergarment) which can prevent the body from the  
25 electromagnetic wave damages and have good wearing feeling

and hand.

The electromagnetic wave shielding knitted material of the invention has higher hand (has a higher G-SOFT value) when using a natural fiber yarn with a higher fineness. On the other hand, the material has a higher electromagnetic wave shielding capability when using a conductive fiber yarn with a lower fineness. However, the fineness of the two types of yarns should be well-balanced, since a great difference in fineness results in unstable knitting operation.

Considering the hand, electromagnetic wave shielding capability and balance in fineness, the natural fiber yarn, when made of cotton, has a cotton count of 30 to 150, preferably 30 to 90, more preferably 40 to 70. The conductive fiber yarn, when being a silver-plated nylon yarn, has a denier (d) of 70 to 210, preferably 70 to 150, more preferably 80 to 120.

Since conductive fiber yarns are generally very expensive, the conductive fiber yarn side of the material of the invention may further comprises an elastic fiber yarn interknitted with the conductive fiber yarn, in order to decrease the amount of the conductive fiber yarn and thereby reduce the cost. A preferred elastic fiber yarn is a single-covered or double-covered yarn comprising a polyurethane thread as a stuffing thread covered with a

nylon thread. However, any yarns having properties equivalent to the single- or double-covered yarn are usable.

As to the fineness of the elastic fiber yarn, an  
5 elastic fiber yarn with a denier (d) less than about 10 is not preferable, since use of such an elastic fiber yarn forms large spaces between the conductive fiber yarns due to insufficient elasticity, resulting in a lowered electromagnetic wave shielding capability. On the other  
10 hand, an elastic fiber yarn with a denier (d) of greater than about 200 is also undesirable, since the elastic fiber yarn is too thick and forms large spaces between the conductive fiber yarns, resulting in a lowered electromagnetic wave shielding capability. Therefore, the  
15 elastic fiber yarn preferably has a denier (d) of about 10 to about 200, more preferably about 70 to about 200.

When interknitting the conductive fiber yarn and the elastic fiber yarn, the proportion of the elastic fiber yarn is preferably greater than 0 but not greater  
20 than  $\frac{2}{3}$ , more preferably greater than  $\frac{1}{3}$  but not greater than  $\frac{1}{2}$ .

The electromagnetic wave shielding knitted material of the invention is suitable for shirts, briefs, knit trunks and other undergarments, T-shirts and like  
25 clothes.

Fig. 5 shows an embodiment of the electromagnetic wave shielding knitted material of the present invention. In Fig. 5, 1 and 2 indicate a conductive fiber yarn and an elastic fiber yarn, respectively. These yarns are interknitted at a ratio of 1:1 (the proportion of the elastic fiber yarn being 1/2) to form a front side of the knitted material. 3 indicates a natural fiber yarn which is knitted to form a back side (the side close to the skin) of the knitted material.

Thus, the knitted material of this embodiment is knitted as a reversible plain knitted fabric. However, the knitted material of the invention is not limited to the reversible plain knitted fabric, but may have any knit structure as long as it has a reversible form.

The electromagnetic wave shielding garment of the invention is designed using an apparatus for measuring and evaluating electromagnetic wave shielding capability comprising a measurement system in the shape of the upper part of the human body in order to maintain the state of a garment as worn on the human body. The apparatus comprises, for example: a signal transmitter for transmitting a high-frequency signal; a transmission antenna connected to the high-frequency signal transmitter for radiating a high-frequency electromagnetic field into a free space; a dummy having a shape and electric

constants (dielectric constant, magnetic permeability, etc.) approximately equal to the human body; a receiving antenna provided at a predetermined position within the dummy for receiving the high-frequency electromagnetic field, the receiving antenna being equivalent in impedance to the human body and a approximately similar in shape to a lead wire of a device surgically implantable in the human body; and a signal receiver connected to the receiving antenna for receiving the high-frequency signal.

10                    Fig. 7 shows an embodiment of the measurement system of the apparatus for measuring and evaluating electromagnetic wave shielding capability used in the present invention. An electromagnetic wave shielding garment 1 is put on a dummy of the human body 2. High-frequency electric power with a predetermined frequency band is applied from the direction of a transmission antenna 3, and high frequency electric power that has passed through the shielding garment 1 is received by a receiving antenna 4 provided at a predetermined position within the dummy 2, thereby measuring the electromagnetic wave shielding capability of the shielding garment 1. A signal transmitter 5 is used to apply high-frequency electric power to the transmission antenna 3, and a signal receiver 6 is used to detect high-frequency electric power that has passed through the shielding garment 1 from the

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receiving antenna 4. As the signal transmitter 5 and the signal receiver 6, a network analyzer or like means serving as both the transmitter and the receiver may be used to output high-frequency electric power with an

5 automatically scanned frequency and detect high-frequency electric power. The dummy 2 is a container molded of FRP (specific dielectric constant 3) filled with a 0.5% NaCl solution which is widely used as a solution equivalent in dielectric constant and other electric constants to the

10 living body. Although this embodiment employs an FRP-molded container and a 0.5% NaCl solution, it is also possible to employ a generally used phantom having a dielectric constant and magnetic permeability equivalent to those of the human body or like living body. In short,

15 any dummy may be utilized as long as it has a shape and electric constants (such as dielectric constant and magnetic permeability) approximately equal to those of the human body and has a structure that permits setting of the receiving antenna 4 at a predetermined position within the

20 dummy. The receiving antenna 4 is an imitation of a lead wire of a cardiac pacemaker, i.e., an implantable device in which the influence of antennas of cellular telephones, radio equipment or like equipment placed in the vicinity of the human body may cause serious trouble. The

25 receiving antenna 4 comprises a coaxial cable and a load

resistor (500  $\Omega$ ) connected at the end of the coaxial cable to attain an impedance equivalent to that of the human body. The coaxial cable preferably has a shape similar to a lead wire of a cardiac pacemaker implanted within the human body. Although this embodiment employs a coaxial cable and a load resistor, it is of course possible to use a cardiac pacemaker lead wire as such. That is to say, any structure can be used as long as it is equivalent in impedance to the human body and similar in shape to a device implantable within the human body. In this embodiment, a cardiac pacemaker is assumed as the implantable to be protected from electromagnetic waves, but the apparatus of the invention can be applied to measure capability of shielding other types of implantable devices from electromagnetic waves, by properly constructing the receiving antenna 4.

With the apparatus of the invention, an electromagnetic wave shielding garment can be put on the dummy to measure capability of shielding electromagnetic waves propagated from a desired position, angle and distance. Using the apparatus, it is possible to design a garment shape to obtain a desired electromagnetic wave shielding capability without the influence of diffraction, infiltration, etc. of electromagnetic waves, and make a garment of the designed shape. The process for designing

the garment shape usually comprises: propagating electromagnetic waves from a desired position, angle and distance to measure the electromagnetic wave amount received by the dummy of the human body wearing the garment and the amount received by the dummy without the garment; and determining the material and shapes of the neck, sleeves, overlapping portion on the body of the electromagnetic wave shielding garment so that the garment has, under the same electromagnetic wave propagation conditions, an electromagnetic wave shielding capability of at least 10 dB, preferably at least 15 dB, more preferably at least 15 dB when the distance between the transmission antenna and the surface of the dummy is 5 cm, and at least 18 dB when the distance is 10 cm, and at least 20 dB when the distance is 20 cm.

The electromagnetic wave shielding garment of the invention is preferably made from a knitted fabric comprising a conductive fiber yarn as described above, a woven fabric, a nonwoven fabric, a mesh fabric and like fabrics having, as the fabric itself, excellent capability of shielding electromagnetic fields in the vicinity. More preferably, the electromagnetic wave shielding garment is made from the electromagnetic wave shielding knitted material of the invention.

The electromagnetic wave shielding garment of

the invention can be obtained by cutting and sewing a fabric having, as the fabric itself, excellent capability of shielding electromagnetic fields in the vicinity as described above. When making the garment, parts

5 constituting the garment are preferably sewn so that the conductive fiber yarn-containing surfaces of the parts are brought into contact with each other to provide conduction. More preferably, the conductive fiber yarn-containing surfaces of the parts are brought into contact with each

10 other and then sewn together with conductive thread. As to the garment shape, a garment having a front button closure or like overlapping portion on the body, such as a collared shirt, is not desirable since, when wearing the garment, gaps are formed at the overlapping portion and

15 allow electromagnetic waves to infiltrate. Also undesirable is a garment in which a conductive material covers only part of the human body, such as an apron for covering only the front side of the human body, since electromagnetic waves diffuse inside the garment around

20 the edge of the conductive material.

Thus, the electromagnetic wave shielding garment of the invention has a shape that can achieve a desired electromagnetic wave shielding capability without the influence of diffraction, infiltration, etc. of

25 electromagnetic waves, the shape being obtained by

measurement with an apparatus for measuring and evaluating electromagnetic wave shielding capability as a garment.

Preferable is a garment for the upper part of the body, in which the whole surface contains a conductive material,

5 and which has no overlapping portion, or has an overlapping portion that does not impair the conductivity nor does form gaps when the wearing the garment.

More preferred is a short-sleeved or long-sleeved undergarment or T-shirt, or a collared shirt  
10 having, at the overlapping portion on the body, a fastener made only of conductive materials. Most preferable is a round-necked or high-necked garment with long or short sleeves with fastened cuffs, since such a garment can prevent infiltration of electromagnetic waves from the  
15 cuffs and neck openings. The material and structure of the electromagnetic wave shielding garment of the invention is not limited to those described above.

#### BEST MODE FOR CARRYING OUT THE INVENTION

20 The following examples are provided to illustrate the present invention in further detail, and are not to limit the scope of the claims of the invention. In the Examples, materials and garments are evaluated by the following methods:

25 (1) Electromagnetic wave shielding capability as a

material (KEC method)

A material (20 cm x 20 cm) to be tested was held between a transmission antenna and a receiving antenna installed within a short distance of each other in a shield box (MB8602B; a product of Anritsu). Electromagnetic waves of different frequencies ranging from 100 MHz to 1 GHz were transmitted, and the attenuation at each frequency was measured using a spectrum analyzer (TR4173; Advantest). The shielding capability was evaluated by the difference (dB) between the measurements with and without the material held between the antennas, at a frequency band for cellular telephones (800 MHz).

(2) Electromagnetic wave shielding capability as a garment

In an electric wave darkroom, the electromagnetic wave shielding capability as a garment was measured, using the measurement system shown in Fig. 7. Specifically stated, high-frequency electric power (800 MHz) was transmitted from a signal transmitter 5 (R3551; Advantest) via a transmission antenna 3 (dipole antenna TR1722; Advantest) installed at a predetermined position, angle and distance, toward a dummy 2 (a human-shaped container molded of FRP with a specific dielectric constant of 3 and filled with a 0.5% NaCl solution widely known as a solution equivalent to the living body in

electric constants such as dielectric constant). The dummy 2 was provided, at a predetermined position therein, with a receiving antenna 4 (an antenna comprising a coaxial cable and a 500  $\Omega$  load resistor connected at the end of the coaxial cable to attain an impedance equivalent to that of the living body, the coaxial cable being similar in shape to a lead wire of a cardiac pacemaker implantable in the human body). The attenuation of transmitted electric power was measured with and without putting an electromagnetic wave shielding garment 1 on the dummy 2, using a signal receiver 6 (spectrum analyzer R3361A; Advantest). As to the position, angle and distance of the transmission antenna 3, the antenna 3 was placed in front of the dummy 2, at the same height as the receiving antenna 4, at such an angle that the element is in the horizontal position, and at a distance of 5 cm, 10 cm or 20 cm from the dummy 2. These conditions produced most significant differences in electromagnetic wave shielding capability as a garment. The shielding capability was evaluated by the difference (dB) between the measurements with and without the electromagnetic wave shielding garment on the dummy.

(3) Electromagnetic field distribution analysis by FDTD method

Using an FDTD analysis simulator (XFDTD 5.0 Bio-

Pro; REMCOM), a dummy having a 300 mm x 100 mm x 500 mm body with a conductivity of 1.43 and a specific dielectric constant of 53, a neck and arms was defined in a free space (600 mm x 400 mm x 700 mm) divided into 10 mm x 10 mm x 10 mm cubes. Then, a 800 MHz sine wave was radiated from a half-wavelength dipole antenna horizontally placed 50 mm ahead of the dummy, to determine magnetic field intensity distribution (Hz components, XZ section) about 10 ns after reaching a steady state at a depth of 15 mm from the body surface of the dummy (the depth at which a pacemaker is implanted). Models of the shielding garments shown in Table 2 were used as analysis models. The models had a conductivity of  $\sigma = 1 \times 10^5 \text{ S/m}$ , which is similar to the conductivity of the shielding garments, and were put on the dummy with a 5 mm gap between the model and the dummy. The evaluation was carried out based on the color of the chest portion in the analysis results (Figs. 8 to 12). The magnetic field intensities indicated by the colors is greater in the order of:

red>orange>yellow>green>blue. Thus, warm colors indicate a great amount of electromagnetic waves.

(4) G-soft evaluation test method:

This test was carried out according to "Standardization and Analysis of Evaluation of Hand" (second edition, Sueo Kawabata, Journal of the Textile



Machinery Society of Japan, July 10, 1980).

KES mechanical properties are defined as follows.

- 1: LT    Linearity of tension
- 2: WT    Tensile energy per unit area
- 5    3: RT    Tensile resilience
- 4: B    Bending rigidity per unit length
- 5: 2HB    Hysteresis
- 6: G    Shear rigidity
- 7: 2HG    Hysteresis at a shear angle of 0.5°
- 10    8: LC    Linearity of compression properties
- 9: WC    Compression energy
- 10: RC    Compression resilience
- 11: MIU    Mean coefficient of friction
- 12: MMD    Mean deviation of coefficient of friction
- 15    13: SMD    Mean deviation of surface roughness
- 14: T    Thickness at a pressure of 0.5 Kg/cm
- 15: W    Weight per unit area

The equation to be used in the calculation is as follows:

$$20 \quad G\text{-soft} = C_0 + \sum_{j=1}^{15} C_j \cdot (X_j - X_j (AV)) / \delta_j \quad (1)$$

Here,  $C_0$  is a constant (=6.253), and  $C_j$ ,  $X_j (AV)$  and  $\delta_j$  are coefficients shown in Table 1.

25    (2) KEC electromagnetic wave shielding capacity evaluation test method:

This test was carried out based on "Science of Textile Consumption", Vol. 40, No. 2 (1999), pp. 100-108, Society of Science of Textile Consumption of Japan.

Example 1

5                   Used were silver-plated nylon multifilament yarns ("X-static" manufactured by Sauguit) of a variety of deniers as conductive fibers, and cotton yarns of variety of counts. The two types of yarns were aligned and fed to a 24.5 gauge plain knitting machine to carry out plating  
10   in all the courses, to prepare knitted materials with a reversible structure comprising a surface layer made of a cotton yarn and a back layer made of a conductive fiber yarn, the two layers being integrally laminated.

                  Using the knitted materials, undergarments were  
15   sewn which had the cotton yarn knit layer on the inside and the conductive fiber knit layer on the outside.

                  Fig. 1 shows the components and performance evaluation results (hand evaluation value of the knitted materials: G-soft; electromagnetic wave shielding  
20   capability (dB) measured by KEC method at 800 MHz). The figure reveals that the reversible knitted materials with a 24.5 gauge plain knit structure had a necessary electromagnetic wave shielding capability (20 dB) regardless of the count of the cotton yarn used, when a  
25   conductive fiber yarn having a denier of at least 100d/34f

was used. The denier of the conductive fiber yarn greatly influences the electromagnetic wave shielding capability.

On the other hand, as shown in Fig. 2, the knitted materials had satisfactory hand for practical use regardless of the denier of the conductive fiber yarn, but the count of the cotton yarn influenced the hand of the knitted materials. Specifically, the greater the cotton count was, the softer the hand became.

Further, wearing tests of the trial products of the undergarments revealed that the trial products had good hand without problems for practical use, had sufficient sweat absorbency, and caused no metal allergy.

#### Example 2

Using the same conductive fiber yarns and cotton yarns as in Example 1, the knitting operation of Example 1 was repeated except that the knit structure was changed to 18.6 gauge rib knitting. Thus, the two types of yarns were aligned and fed to a rib knitting machine to carry out plating in all the courses, to prepare reversible knitted materials comprising a surface layer made of a cotton yarn and a back layer made of a conductive fiber yarn. Using this knitted materials, shirts (undergarments) for wearing tests were sewn in the same manner as in Example 1. Further, performance evaluation was carried out in the same manner as in Example 1.

Fig. 3 shows the evaluation results, which were similar to the evaluation results obtained in Example 1. Fig. 3 also reveals that, when the conductive fiber knit yarn layer is made by rib knitting, it is necessary to use a conductive fiber yarn of at least 70d/34f to achieve a required electromagnetic wave shielding capability (20 dB). Thus, the denier of the conductive fiber yarn required to obtain a necessary shielding capability in this Example is lower than in Example 1.

Other performance evaluation showed similar results to the results obtained in Example 1, as presented in Fig. 4.

With the above structure, electromagnetic wave shielding knitted materials according to the present invention have good KES hand evaluation value (G-Soft) of greater than 6 and a high sweat absorbency, and enables provision of always wearable knit undergarments that protect the human body from electromagnetic wave damage with high productivity.

Further, using the reversible knitted materials of the invention, garments can be prepared in which a conductive fiber is covered by a clothing fiber, so that the conductive fiber does not come into direct contact with the skin and causes no skin disorder owing to metal allergy.

Table 1

j=		Basic mechanical properties of fabric	Unit	Cj	Xj (AV)	6j
1	LT	Linearity of tension	Dimensionless	-0.4202	0.7756	0.0679
2	WT	Tensile energy per unit area	gf · cm/cm <sup>2</sup>	-0.0401	0.6808	0.2557
3	RT	Tensile resilience	%	-0.0443	1.5952	0.0639
4	B	Bending rigidity per unit length	gf · cm <sup>2</sup> /cm	-1.4418	-1.7851	0.3288
5	2HB	Hysteresis	gf · cm/cm	0.1699	-1.6590	0.3213
6	G	Shear rigidity	gf/cm · deg	0.0251	-0.4000	0.1276
7	2HG	Hysteresis at a shear angle of 0.5°	gf/cm	-0.1357	0.0444	0.1486
8	LC	Linearity of compression properties	Dimensionless	-0.0005	0.6337	0.0692
9	WC	Compression energy	gf · cm/cm <sup>2</sup>	0.5584	-0.9937	0.1526
10	RC	Compression resilience	%	0.3396	38.1224	5.6815
11	MIU	Mean coefficient of friction	Dimensionless	-0.2220	-0.5952	0.0861
12	MMD	Mean deviation of coefficient of friction	Dimensionless	-0.0867	-1.5999	0.2018
13	SMD	Mean deviation of surface roughness	μm	-0.1525	0.9280	0.1999
14	T	Thickness at a pressure of 0.5 Kgf/cm	Mm	-0.2283	0.0638	0.1361
15	W	Weight per unit area	mg/cm <sup>2</sup>	0.3016	17.3383	5.0040

Example 3

Used were a 200 d silver-plated nylon yarn ("X-  
STATIC" manufactured by SAUQUIT) as a conductive fiber  
yarn, a single-covered yarn comprising a 20 d polyurethane  
5 stuffing thread covered with a 30 d nylon thread as an  
elastic fiber yarn, and a No. 30 count cotton yarn as a  
natural fiber yarn. The yarns were knitted to prepare a  
reversible plain knitted material of the present invention,  
which comprised a surface side made of the silver-plated  
10 nylon yarn and the single-covered yarn interknitted at a  
ratio of 1:1 (the proportion of the single-covered yarn  
being 1/2) and a back side (the side that would come into  
contact with the skin) made of the cotton yarn. The  
obtained material was cut and sewn in a routine manner to  
15 obtain an undergarment. Fig. 6 shows the relation between  
electromagnetic wave shielding capability and cost of the  
undergarment. The electromagnetic wave shielding  
capability is expressed in a value relative to a reference  
sample, based on the magnetic field shielding ratio at 800  
20 MHz measured according to the KEC (Kansai Electronic  
Industry Development Center) method. The cost is also  
expressed in a value relative to the reference sample.  
The reference sample was an undergarment prepared in the  
same manner as above except that the surface side was made  
25 by interknitting the silver-plated nylon yarn and the

single-covered yarn at a ratio of 1:0 (the proportion of the single-covered yarn being 0).

Example 4

An undergarment was prepared by following the  
5 procedure of Example 3 except that the silver-plated nylon  
yarn and the single-covered yarn were interknitted at a  
ratio of 1:2 (the proportion of the single-covered yarn  
being 2/3). The results are shown in Fig. 6 in the same  
manner as the results of Example 3.

10 (Comparative Example 1)

An undergarment was prepared by following the  
procedure of Example 3, except that the silver-plated  
nylon yarn and the single-covered yarn were interknitted  
at a ratio of 1:3 (the proportion of the single-covered  
15 yarn being 3/4). The results are shown in Fig. 6 in the  
same manner as the results of Example 3.

(Comparative Example 2)

An undergarment was prepared by following the  
procedure of Example 3, except that the silver-plated  
20 nylon yarn and the single-covered yarn were interknitted  
at a ratio of 1:4 (the proportion of the single-covered  
yarn being 4/5). The results are shown in Fig. 6 in the  
same manner as the results of Example 3.

The results obtained above reveal that the  
25 undergarment obtained in Example 3 (silver-plated nylon

yarn: single-covered yarn=1:1) has an equivalent electromagnetic wave shielding capability but costs 30% less, as compared with the reference sample (silver-plated nylon yarn: single-covered yarn=1:0). Although the

5 undergarment of Example 4 (silver-plated nylon yarn: single-covered yarn=1:2) has about 20% reduced electromagnetic wave shielding capability, this does not cause any problems in the case where moderate electromagnetic wave shielding capability is required.

10 Further, the undergarment of Example 4 realizes remarkable cost reduction (50%). The undergarments of Comparative Examples 1 and 2 have substantially no electromagnetic wave shielding capability, although they attain cost reduction.

15 Therefore, the present invention provides an electromagnetic wave shielding knitted material and undergarment that do not cause unpleasant feeling when worn, or skin disorder due to metal allergy. The material and undergarment realize significant cost  
20 reduction because of reduction in conduct fiber amount, while maintaining the electromagnetic wave shielding capability.

The material and undergarment of the invention not only protect the human body from the influence of  
25 electromagnetic waves, but also effectively prevent



electromagnetic waves from causing malfunction of a pacemaker or other medical devices implanted in the human body.

Table 2 shows the types of models and individual settings used in Example 5 and 6 and Comparative Example 3 to 5.

Table 2

Type of model	Individual setting
Example 5 (short-sleeved, round-necked undershirt)	<ul style="list-style-type: none"><li>• Has a linear neck portion</li><li>• Covers the whole circumference of the torso</li></ul>
Example 6 (short-sleeved, V-necked undershirt)	<ul style="list-style-type: none"><li>• Neck depth: 80 mm</li><li>• Covers the whole circumference of the torso</li></ul>
Comparative Example 3 (short-sleeved collard shirt)	<ul style="list-style-type: none"><li>• Width of the front overlapping portion: 30 mm; Gap in the overlapping portion: 5 mm; Spaces between buttons (for fastening the right and left sides of the front at the centerline of the overlapping portion): 80 mm (the first button is at 10 mm below the upper edge of the shirt)</li><li>• Except for the gap in overlapping portion, covers the whole circumference of the torso</li></ul>
Comparative Example 4 (sleeveless vest)	<ul style="list-style-type: none"><li>• No overlapping portion in the right and left sides of the front (gap: 5 mm)</li><li>• Except for the gap, covers the whole circumference of the torso</li></ul>
Comparative Example 5 (without shielding garment)	

(Example 5)

Used were a silver-plated nylon fiber yarn ("X-static" manufactured by SAUQUIT, 100 denier/34 filaments) as a conductive fiber yarn, an elastic fiber yarn (a  
5 single-covered yarn comprising a 20 d polyurethane thread as a stuffing thread covered with a 30 d nylon thread), and No. 80 count cotton yarn. These yarns are knitted to prepare a reversible plain knitted material which comprised a surface side made of the silver-plated nylon  
10 yarn and the single-covered yarn interknitted at a ratio of 1:1, and a back side (the side that would come into contact with the skin) made of the cotton yarn. The obtained material was cut and sewn in a routine manner to obtain a short-sleeved, round-necked undergarment. The  
15 undergarment had neck tapes and sleeve tapes made of the same knitted material and folded in such a manner that the cotton yarn layers of these tapes came to the side to be in contact with the skin. The tapes were sewn so that the silver-plated nylon-containing layers of these tapes came  
20 into contact with the surface side of the body of the undergarment.

The reversible plain knitted material was tested for electromagnetic wave shielding capability by the method (1) described above. The short-sleeved, round-  
25 necked undergarment was put on the dummy and then tested

for electromagnetic wave shielding capability as a garment by the above method (2). Table 3 shows the test results. Fig. 8 shows the result of electromagnetic field distribution analysis of a model of the short-sleeved round-necked undergarment carried out by the above method (3).

Table 3

	Electromagnetic wave shielding capability as a material		Electromagnetic wave shielding capability as a garment		
	Electric field shielding capability (dB)	Magnetic field shielding capability (dB)	Distance to the dummy		
			5 cm (dB)	10 cm (dB)	20 cm (dB)
Ex.5	44	23	22	23	28
Ex.6			16	18	21
Comp. Ex.3	37	16	-1	1	8
Comp. Ex.4	36	17	-2	-1	6

10 (Example 6)

Using the reversible plain knitted material obtained in Example 5, a short-sleeved, V-necked undergarment was prepared by following the procedure of Example 5 except that the shape of the neck was changed to V neck. The short-sleeved, V-necked undergarment was put on the dummy, and tested for electromagnetic wave

shielding capability as a garment. Table 3 shows the test results. Fig. 9 shows the result of electromagnetic field distribution analysis of a model of the short-sleeved V-necked undergarment carried out by the above method (3).

5 (Comparative Example 3)

A collared shirt type electromagnetic wave shielding garment (a cardiac pacemaker protection garment against cellular telephone radiation, manufactured by MHP council) was used which was made of a plain weave fabric comprising, as the warp and weft, a conductive fiber yarn ("X-age" manufactured by Kanebo Spinning Corporation) containing a silver-plated nylon fiber ("X-static" manufactured by SAUQUIT). The weave fabric was tested for electromagnetic wave shielding capability as a material by the above method (1). The collard shirt type electromagnetic wave shielding garment was put on the dummy, and tested for electromagnetic wave shielding capability as a garment by the above method (2). Table 3 shows the results. Fig. 10 shows the result of electromagnetic field distribution analysis of a model of the collard shirt type electromagnetic wave shielding garment carried out by the above method (3).

(Comparative Example 4)

A vest type electromagnetic wave shielding garment ("MG Vest" manufactured by Freesia) comprising a

mesh fabric comprising a silver-coated polyester fiber was used. The mesh fabric was tested for electromagnetic wave shielding capability as a material by the above method (1). The vest type electromagnetic wave shielding garment was put on the dummy and tested for electromagnetic wave shielding capability as a garment by the above method (2). Table 3 shows the test results. Fig. 11 shows the result of electromagnetic field distribution analysis of a model of the vest type electromagnetic wave shielding garment carried out by the above method (3).

(Comparative Example 5)

An electromagnetic field distribution analysis was carried out using the dummy without an electromagnetic wave shielding garment. Fig. 12 shows the result.

As is apparent from Table 3, the reversible plain knitted material obtained in Example 5 is similar (slightly superior) in electromagnetic wave shielding capability as a material, to the weave fabric of Comparative Example 3 and the mesh fabric of Comparative Example 4. On the other hand, the electromagnetic wave shielding capabilities as a garment achieved in Examples 5 and 6 are remarkably superior, demonstrating that the electromagnetic wave shielding garment of the present invention is properly designed and made by using the apparatus for measuring and evaluating electromagnetic

wave shielding capability as a garment.

Further, in the FDTD electromagnetic field distribution analysis results (Figs. 8 to 12), the colors at the chest portions of the short-sleeved round-necked undergarment model of Example 5 (Fig. 8) and the short-sleeved V-necked undergarment model of Example 6 (Fig. 9) are green, yellow and orange, indicating that these models securely shield electromagnetic waves.

In contrast, the colors at the chest portions of the collared shirt type electromagnetic wave shielding garment model of Comparative Example 3 (Fig. 10) and the vest type electromagnetic wave shielding garment model of Comparative Example 4 (Fig. 11) are orange and red, which are approximately similar to the colors of the chest portion of the dummy without an electromagnetic wave shielding garment in Comparative Example 5 (Fig. 12). Thus, the garments of Comparative Examples have substantially no shielding effect against electromagnetic waves. These results agree well with the above measurement results of the electromagnetic field shielding capability as a garment.

As discussed above, the electromagnetic wave shielding garment according to the present invention prevents the influence on the human body of electromagnetic waves caused by high-frequency

**Table 1**

Year	Number of cases	Percentage of total cases
1970	10	1.8
1971	15	2.6
1972	20	3.5
1973	25	4.3
1974	30	5.1
1975	35	5.9
1976	40	6.7
1977	45	7.5
1978	50	8.3
1979	55	8.9
1980	60	9.5
1981	65	10.1
1982	70	10.7
1983	75	11.3
1984	80	11.9
1985	85	12.5
1986	90	13.1
1987	95	13.7
1988	100	14.3
1989	105	14.9
1990	110	15.5
1991	115	16.1
1992	120	16.7
1993	125	17.3
1994	130	17.9
1995	135	18.5
1996	140	19.1
1997	145	19.7
1998	150	20.3
1999	155	20.9
2000	160	21.5
2001	165	22.1
2002	170	22.7
2003	175	23.3
2004	180	23.9
2005	185	24.5
2006	190	25.1
2007	195	25.7
2008	200	26.3
2009	205	26.9
2010	210	27.5
2011	215	28.1
2012	220	28.7
2013	225	29.3
2014	230	29.9
2015	235	30.5
2016	240	31.1
2017	245	31.7
2018	250	32.3
2019	255	32.9
2020	260	33.5
2021	265	34.1
2022	270	34.7
2023	275	35.3
2024	280	35.9
2025	285	36.5
2026	290	37.1
2027	295	37.7
2028	300	38.3
2029	305	38.9
2030	310	39.5
2031	315	40.1
2032	320	40.7
2033	325	41.3
2034	330	41.9
2035	335	42.5
2036	340	43.1
2037	345	43.7
2038	350	44.3
2039	355	44.9
2040	360	45.5
2041	365	46.1
2042	370	46.7
2043	375	47.3
2044	380	47.9
2045	385	48.5
2046	390	49.1
2047	395	49.7
2048	400	50.3
2049	405	50.9
2050	410	51.5
2051	415	52.1
2052	420	52.7
2053	425	53.3
2054	430	53.9
2055	435	54.5
2056	440	55.1
2057	445	55.7
2058	450	56.3
2059	455	56.9
2060	460	57.5
2061	465	58.1
2062	470	58.7
2063	475	59.3
2064	480	59.9
2065	485	60.5
2066	490	61.1
2067	495	61.7
2068	500	62.3
2069	505	62.9
2070	510	63.5
2071	515	64.1
2072	520	64.7
2073	525	65.3
2074	530	65.9
2075	535	66.5
2076	540	67.1
2077	545	67.7
2078	550	68.3
2079	555	68.9
2080	560	69.5
2081	565	70.1
2082	570	70.7
2083	575	71.3
2084	580	71.9
2085	585	72.5
2086	590	73.1
2087	595	73.7
2088	600	74.3
2089	605	74.9
2090	610	75.5
2091	615	76.1
2092	620	76.7
2093	625	77.3
2094	630	77.9
2095	635	78.5
2096	640	79.1
2097	645	79.7
2098	650	80.3
2099	655	80.9
2100	660	81.5